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Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries

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HIGHLIGHTS

- The study presents the investigation of biomass energy consumption and environmental pollution in BRICS countries.
- Biomass energy consumption help in to reduce environmental pollution.
- N-shaped relationship is found between income and pollution.
- Besides, the trade openness contributes to environmental pollution.

GRAPHICAL ABSTRACT

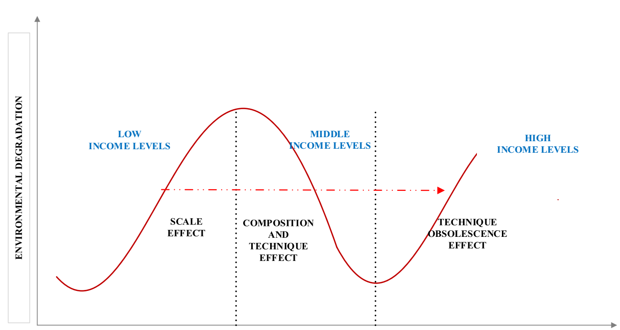

Figure 2: Environmental Kuznets Curve for more detail refer to (Sarkodie and Strezov, 2019)

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ABSTRACT

The dilemma of rising environmental pollution in recent decades has raised the demand for clean energy sources. However, some newly developed energy sources, such as biomass energy, may or may not contribute to reducing environmental stress. This study investigates biomass energy consumption and environmental pollution in BRICS countries by applying the generalized system method of moment (GMM) model for empirical estimation from 1992 to 2013. The results show that biomass energy consumption behaves as a clean energy source in reducing environmental pollution. The study also found support for the presence of an N-shaped relationship between income and pollution and found that trade openness is the only factor that contributes to pollution in BRICS countries. These results can assist policymakers in considering biomass energy as a clean source of energy in the effort to achieve both energy security and environmental sustainability.

1. Introduction

Over the last few decades, rapid economic growth around the globe has increased energy consumption and environmental degradation. The relationships among energy, the environment, and income have

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motivated the policy analysts and economists to investigate the causality of economic growth, aspects of the environmental, and energy consumption (Tiba and Omri, 2017). The growing energy demand has led to frequent use of fossil-fuel-based energy sources (coal, oil, and gas), which has raised serious environmental concerns. However, renewable energy sources—bioenergy, hydropower, geothermal energy, solar energy, wind energy, and ocean (tide and wave) energy—are the best approach to combatting environmental challenges (Owusu and Asumadu-Sarkodie, 2016). The intensified energy consumption that has followed efforts to increase economic growth improve living standards has resulted in high carbon dioxide (CO_2) emissions, increasing the environmental risks related to climate change. The significant rise in CO_2 emissions is due to increased energy consumption (Adewuyi and Awodumi, 2017). CO_2 emissions are among the largest contributors to environmental pollution and global warming and are a serious concern for today's world and the future of the planet (Bilgili et al., 2016). Environmental quality and economic growth have been considered a tradeoff, but the increasing demand for energy must be approached in a way that ensures sustainable economic growth while avoiding environmental damage (e.g., deforestation, climate change, water pollution, loss of biodiversity).

For three decades, economic growth has continued in newly industrialized and transition economies like the BRICS countries (Brazil, Russia, India, China, and South Africa). BRICS countries' gross domestic product (GDP) rose from US$2187 billion (in constant 2010 US$) in 1985 to US$16,266 billion in 2016, an average 6.5% annual growth rate. The BRICS countries hold 40% of the world population, contribute 21% of the world's GDP, consume 40% of the world's energy, and contribute to a considerable proportion of global CO_2 emissions. Their fast economic growth requires energy imports to meet energy requirements, but their environmental challenges rise at the same time. The BRICS countries need to counter these challenges by using alternative energy sources for future household, commercial, and industrial energy needs. Biomass energy is easily available, and its production can be started quickly in the region, which is why BRICS countries prefer biomass energy to be part of the policy agenda of sustainable development (Shahbaz et al., 2016, 2018). In the BRICS countries, biomass energy is composed of three main categories: wood, non-wood, and waste. Biomass energy accounts for 36.8% of the total energy consumption in these countries (Bildirici, 2014; Shahbaz et al., 2016), so they would benefit from an investigation into whether biomass energy sources can address environmental degradation by serving as clean energy sources. The trend of biomass energy use in the BRICS countries is shown in Fig. 1.

Because of rising CO_2 emissions, there is enormous demand for clean energy sources (Dong et al., 2018). Biomass energy may contribute to the need for energy and environmental sustainability (Dogan and Inglesi-Lotz, 2017), but research findings concerning its relationship with economic growth and CO_2 emissions are ambiguous (Adewuyi and Awodumi, 2017). For example, Bilgili et al. (2016) found that biomass energy mitigates CO_2 emissions, while Solarin et al. (2018) recommended that biomass energy is like fossil fuels in generating CO_2 emissions. Shahbaz et al. (2018) claimed that biomass energy accelerates the rate of CO_2 emissions, while in another study Shahbaz et al. (2017) suggested that biomass energy consumption mitigates the level of pollution. Dogan and Inglesi-Lotz (2017) highlighted that biomass energy is helpful in reducing CO_2 emissions. Little has been discussed in the literature regarding the role of biomass energy in environmental pollution, but these studies findings are ambiguous regarding whether biomass energy consumption lowers CO_2 emissions.

Against this background, this study analyzes the effect of biomass energy consumption on CO_2 emissions for BRICS economies in an effort to inform policies related to sustainable growth and environmental protection. This study incorporates urbanization, the Kyoto protocol, and foreign direct investment (FDI), and uses the trade ratio as an explanatory variable to avoid specification bias in the empirical model.

The study makes several contributions to the literature. To the best of our knowledge, no research has focused on the effect of biomass energy consumption on CO_2emissions in BRICS countries, despite the heavy reliance on biomass energy in the BRICS countries' economies. The BRICS region is at a crossroads in terms of risk to its energy security and environmental sustainability, so it is under external and internal pressure to continue the current pace of economic growth while also reducing pollution intensity. Only one study, Shahbaz et al. (2016), has focused on the nexus between biomass consumption and economic growth in BRICS countries, but the study did not take CO_2 emissions into account in its analysis of the relationship between biomass energy and economic growth. Therefore, the present study examines the role of biomass energy use in CO_2 emissions to inform policymakers in their decisions regarding sustainable development. In addition, previous

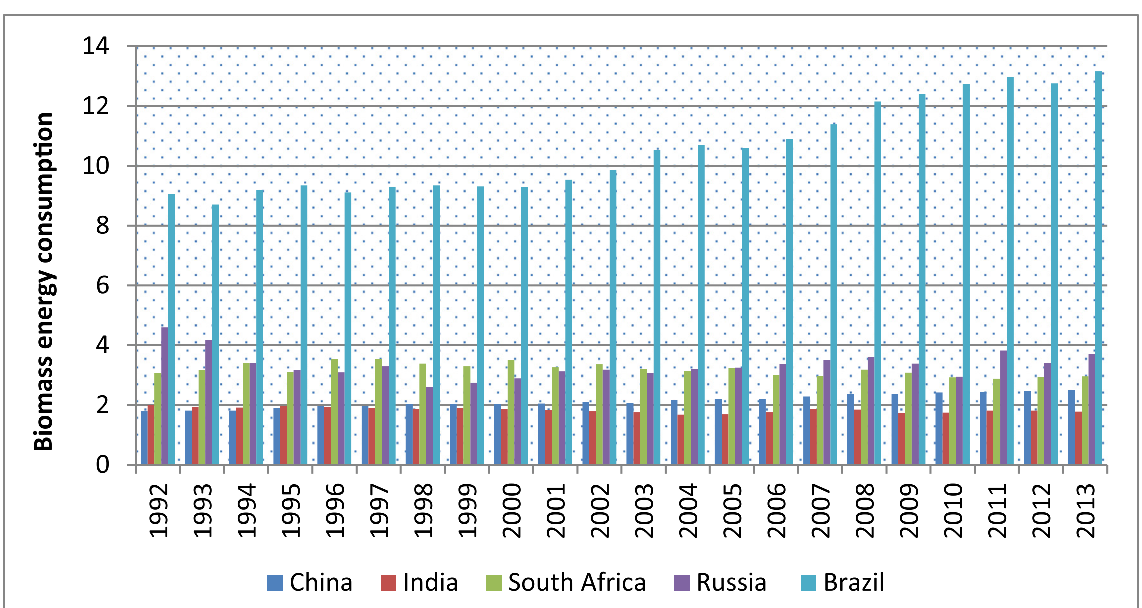

Fig. 1. Trend in biomass energy consumption per capita in BRICS economies 1992–2013.

studies have ignored some important variables that are included in the present study's model: FDI, trade openness, urbanization, and the Kyoto protocol. This study should assist policymakers in BRICS countries in considering the role of biomass energy in environmental pollution and in pursuing sustainable energy-driven economic growth and development.

The remainder of the study proceeds as follows. Section 2 provides a literature review, while Section 3 describes the model construction and data source. Section 4 explains the econometric strategy, and Section 5 presents the analysis results, Section 6 discusses the results discussion, and Section 7 concludes the study.

2. Literature review

The energy-growth-environment nexus has been studied widely for single countries, panel data and cross-region analysis. The Kuznets' curve theory, introduced in 1955, has seen immense attention in the literature and has been hotly debated, particularly by environmental economists Grossman and Krueger (1991) were first to study the relationship between economic growth and pollution, finding that sulfur dioxide and dark-matter concentrations increase to a certain level and then decrease once income crosses a threshold level. Panayotou (1993) defined the relationship between GDP per capita and environmental pollution indicators for the first time as the Environmental Kuznets Curve (EKC) (see Fig. 2).

Beginning in the year 2000, energy consumption was incorporated into the EKC model. Since then, a large number of studies have investigated the EKC hypothesis by including energy consumption in the model. These studies can be divided into studies that use aggregate energy consumption in the model and studies that disaggregate energy consumption. Studies that have aggregated energy consumption into the EKC model are Al-Mulali et al. (2015a, b), Danish et al. (2017b), Farhani and Ozturk (2015), Sarkodie and Strezov (2019a), Zaman et al. (2016), and Zhang et al. (2017). Another group of scholars has investigated the roles of renewable and non-renewable energy consumption in environmental degradation, and nearly all have agreed that renewable energy reduces environmental stress while non-renewable energy contributes to environmental pollution (Cherni and Essaber Jouini, 2017; Danish et al., 2017a; Destek and Aslan, 2017; Dogan and Ozturk, 2017; Ito, 2017; Sarkodie and Adams, 2018). Because of the rising environmental stress from CO_2 emissions, clean energy has been the focus of recent studies, with some finding that biomass energy contributes to reducing environmental stress by mitigating CO_2 emissions (Bilgili et al., 2016; Dogan and Inglesi-Lotz, 2017; Katircioglu, 2015; Shahbaz et al., 2017), others finding that biomass energy degrades environmental quality (Shahbaz et al., 2018; Solarin et al., 2018), and Adewuyi and Awodumi (2017) concluding that biomass energy has a heterogeneous effect on environmental pollution in West African countries. Recently, Baležentis et al. (2019) analyzed the role of biomass energy using EKC modeling for countries in the European Union (EU) and found that the use of biomass energy lowers environmental pollution and has a higher impact than other renewables do.

Clearly, research has not reached a consensus on whether biomass energy contributes to or mitigates CO_2 emissions. Most studies have used panel data, such as data on G-7 countries, West African countries, and developing countries, but the current study is the first attempt to investigate the effect of biomass energy on CO_2 emission in BRICS economies. In addition, the study considers the N-shaped relationship between economic growth and CO_2 emissions in BRICS economies for the first time.

3. Model construction and data source

3.1. Model construction

In line with Shahbaz et al. (2017), we modeled the impact of biomass energy and economic growth on CO_2 emissions while controlling for urbanization, trade and FDI, and the Kyoto protocol. The relationship among the underlying variables is expressed as:

$$Ln(CO_2)_{it} = \alpha_0 + \alpha_1(LnGDP)_{it} + \alpha_2\left(LnGDP^2\right)_{it} + \alpha_3\left(LnGDP^3\right)_{it} + \alpha_5(LnBIO)_{it} + \alpha_5(LnTR)_{it} + \alpha_6(LnURB)_{it} + \alpha_7(LnFDI)_{it} + K + \mu_{it} \quad (1)$$

where CO_2 is carbon dioxide emissions per capita, GDP is gross domestic product per capita (a proxy for economic growth), TR is the trade ratio, BIO is biomass energy, FDI is foreign direct investment, URB is urbanization, K is the Kyoto protocol, i and t are country and time, respectively,

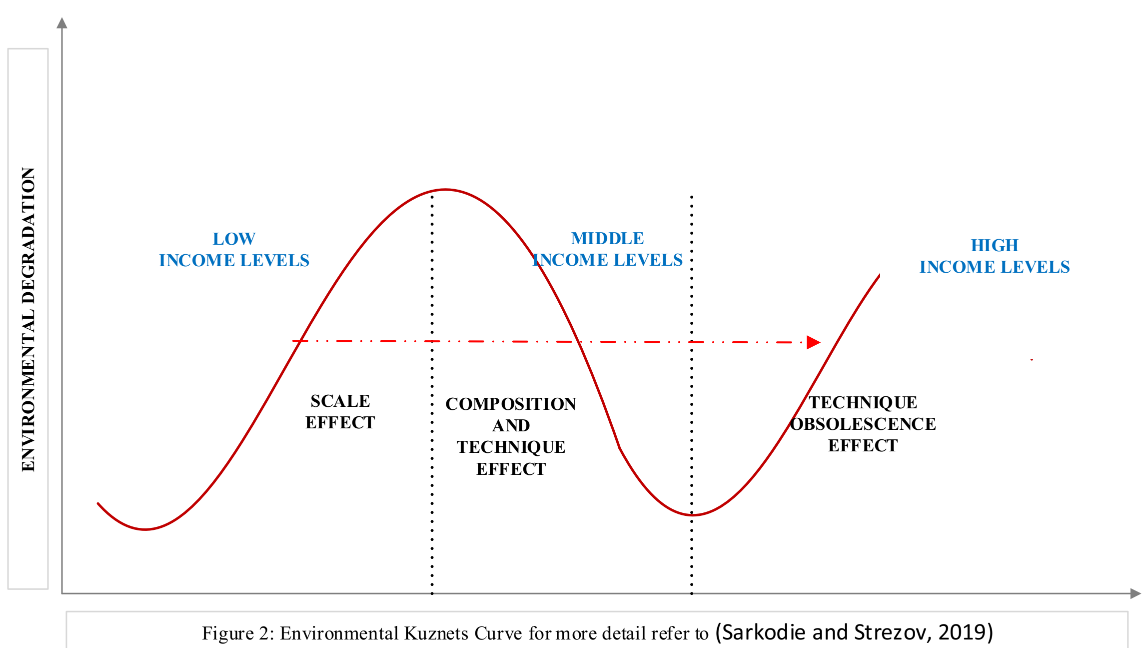

Fig. 2. Environmental Kuznets Curve for more detail refer to (Sarkodie and Strezov, 2019a, b).

and μ is the disturbance term. The relationship between economic growth and pollution has been studied as taking an inverted U-shape in the literature such that, if $\alpha_1 > 0$ and $\alpha_2 < 0$, the inverted U-shaped relationship supports the EKC hypothesis. However, the quadratic relationship between economic growth and pollution gives ambiguous results because the pollution level becomes zero or negative after income achieves a certain threshold. Therefore, Moomaw and Unruh (1997) suggested a cubic relationship between income per capita and pollution. For instance $\alpha_1 > 0$, $\alpha_2 < 0$, and $\alpha_3 > 0$ it suggest an N-shaped relationship between income and pollution, which is part of our empirical estimation as well. The expected sign of α_4 is negative, indicating that biomass energy reduce pollution, as otherwise it would behave like fossil fuels, which that hurt the environment (Bilgili et al., 2016; Katircioglu, 2015; Shahbaz et al., 2017).

3.2. Data source and description of variables

The dataset used in this study refers to BRICS economics from 1992 to 2013, a period chosen based on data availability. The data on CO_2 emissions are measured in million metric tons per capita. Economic growth is measured as GDP per capita (in constant 2010 USD), FDI is measured as net inflow (as a percent of GDP), the trade ratio is measured as the sum of export and imports as a percent of GDP, and urbanization is measured as the urban population as a percent of total population. The data on CO_2 emissions, GDP per capita, FDI, urbanization, and trade are gathered from the World Development Indicator website, a database of the World Bank. The Kyoto protocol is a dummy variable, where the years after 1996 are given a value of 1, and zero otherwise. The data for biomass refer to biomass extraction as a proxy for biomass energy consumption and are collected from the Global Material Flows Database. The boxplots for the variables economic growth (lnGDP), square of GDP (lnGDP^2), and CO_2 emissions (lnCO_2), FDI (lnFDI), trade openness (lnTR), and biomass energy (lnBIO) are shown in Fig. 3.

4. Econometric methodology

4.1. Panel unit root test

The first step of the econometric analysis is to determine the stationarity of the series, especially the model containing several economic variables, to ensure estimates are reliable. For panel data analysis, the unit root tests are divided into first-generation and second-generation panel unit root tests (Danish et al., 2018a). The first-generation of panel unit root tests include the Levin Lin Chu (LLC) and Hadri, Breitung tests, which cannot counter cross-sectional dependence. Second-generation panel unit tests like the IPS (IM Pesaran Shin) test, the Fisher ADF test, and the Fisher PP can lessen the problem of homogeneity (Danish et al., 2018b; Wang et al., 2018). The second generation also includes recently developed unit root tests like CIPS and CADF (Pesaran, 2007), which account for cross-sectional dependence because the income and CO_2 emissions levels vary significantly among the BRICS countries. Therefore, for the second-generation panel unit root tests are appropriate for this study, which is based on the assumption of homogeneity and cross-sectional dependence.

4.2. Generalized method of moment model

This empirical work investigates the relationship between biomass energy consumption and environmental pollution. The study treats

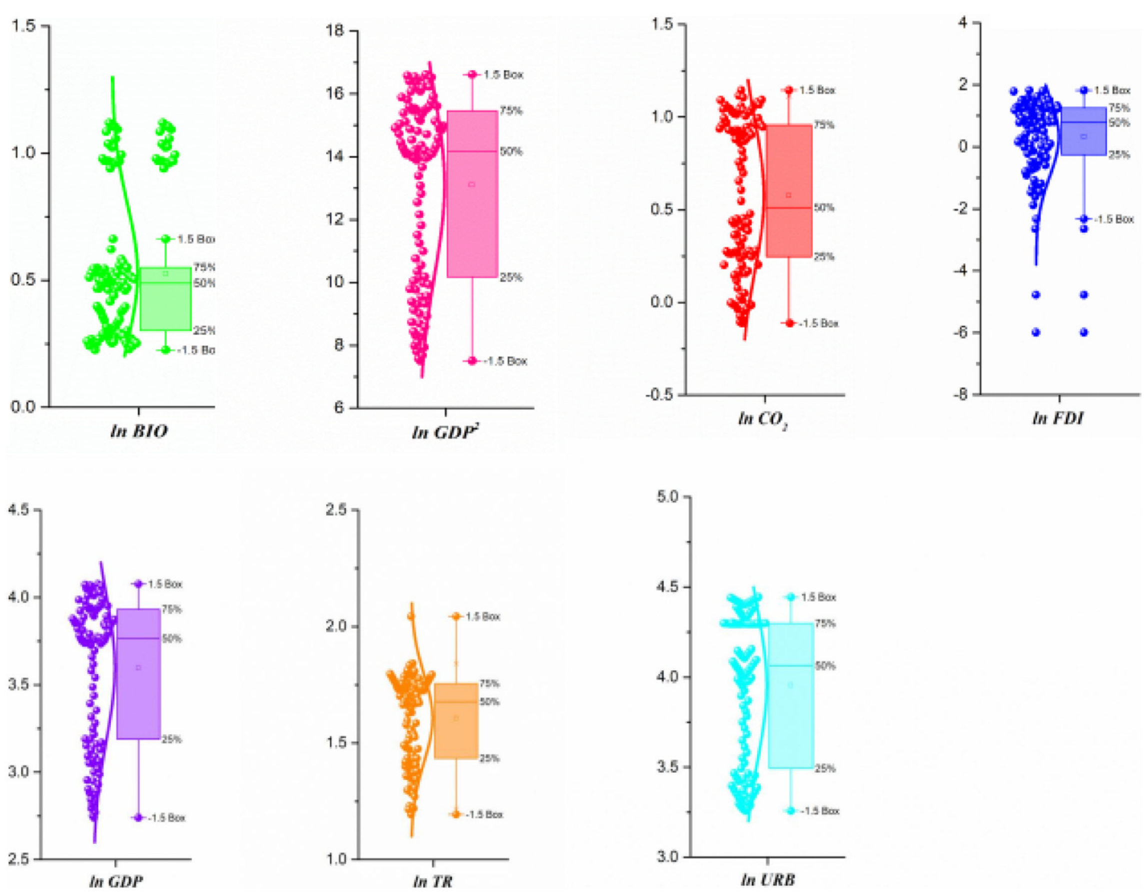

Fig. 3. Boxplots for the variables lnGDP, lnGDP^2, lnCO_2, lnFDI, lnTR, and lnBIO.

CO_2 emissions as an endogenous variable, while biomass energy consumption, economic growth, urbanization, FDI, the Kyoto protocol, and the trade ratio are treated as exogenous variables. The correlation between the disturbance term and the endogenous variables leads to the possibility of simultaneity and endogeneity bias. Applying ordinary least squares (OLS) regressions in the presence of these issues would produce biased and unreliable estimates, resulting in a violation of one of the assumptions of classical linear regression models. Long-run panel data estimation methods are also inapplicable here, so to ensure reliable and precise empirical analyses, we employ the generalized method of moment (GMM) approach. The GMM panel data estimation strategy was introduced by Arellano and Bond (1991), who argued that, in a dynamic panel model, additional instruments can be achieved by using the orthogonal condition between the lag value of the dependent variable and the error term. Thus, the instruments eradicate the correlation between the independent variables and the disturbances.

The GMM estimator was prioritized for this study over other estimators because the GMM model helps to counter cross-country effects by applying first-order differentiation and by controlling for the possible endogeneity of the explanatory variables through the use of the orthogonal condition between the lag value of the dependent variable and the error term (Halkos, 2003). As a result, the estimation is reliable and consistent.

5. Results analysis

5.1. Descriptive statistic

Table 1 shows a descriptive analysis of the variables. Urbanization (URB) is the least volatile of all the variables. Biomass energy (BIO) is less volatile than economic growth (GDP), and CO_2emissions (CO_2), but CO_2 is less volatile than FDI. The trade ratio (TR) is less volatile than CO_2, BIO, FDI, and GDP. All variables exhibit a considerable degree of standard deviation.

The correlation matrix in Table 1 suggests that, while all variables except BIO and FDI have a positive association with CO_2, this result sounds deceptive. The descriptive statistics do not reveal causation, while would require inferential statistics for empirical investigation of the causal relationship between CO_2 and the predictor variables under study.

5.2. Panel unit root tests

Because the GDP and CO_2 levels vary significantly among BRICS countries, a group of second-generation panel unit roots test is appropriate. The results, shown in Table 2, indicate that the variables under consideration are not stationary at level but become stationary after taking the first difference. Thus, BIO, GDP, CO_2, URB, FDI, and TR are integrated at the first order I(1), and we can go on to regression estimates.

5.3. Regression results

The GMM econometric strategy is applied to get regression coefficients. This study takes CO_2 as an endogenous variable and GDP, BIO, FDI, TR, and URB as exogenous variables. The correlation table shows high correlations between several variables, so there may be an endogenous bias that restricts the use of OLS regression to avoid inconsistent and biased parameter estimates. Therefore, to avoid possible endogeneity problems, we use the GMM estimation method, and the results are shown in Table 3.

As Table 3 shows, the coefficient of GDP is positive, the coefficient of GDP^2 is negative, and the coefficient of GDP cubed is positive (in all six models), suggesting that GDP's effect on CO_2 is not stable. In other words, the positive-negative-positive relationship between income and pollution supports the N-shaped curve, perhaps because governmental policies have inclined toward economic development, so CO_2 emissions are still increasing rapidly along with economic growth.

The environmental impact of biomass energy (logBIO) is negative and significant in all five models, so biomass energy is negatively related to CO_2 emissions. This result suggests that biomass energy consumption mitigates the level of pollution by reducing CO_2 emissions, which also reduces environmental stress.

The relationship between the Kyoto protocol and CO_2 emissions is negative and significant, suggesting that a significant decrease in CO_2 emissions took place the BRICS countries after the Kyoto protocol agreement. The results also show that the impact of trade on CO_2 emission is positive and significant, so increased international trade accelerates the level of pollution by contributing to the rate of CO_2 emissions. Trade is the only factor that increases environmental stress in the BRICS countries, as the other explanatory variables, URB and FDI, have insignificant impacts on CO_2 emissions, so urbanization and FDI do not play a significant role in environmental quality. Therefore, all variables under consideration except URB and FDI have a significant effect on CO^2 emissions.

5.4. Robustness check

The study uses the main information criteria to check the validity of the GMM model. The results in Table 3 show that we strongly reject the second-order Arellano and Bond autocorrelation test's (AR [2]) null hypothesis, which proposes the absence of autocorrelation in the corresponding model. The results of Hansen over-identification restrictions

Table 1
Results of descriptive statistic and correlation matrix.

	$LOGCO_2$	LOGBIO	LOGFDI	LOGGDP	LOGTR	LOGURB	KP
Mean	0.575211	0.526941	0.140948	3.596552	1.606428	1.717748	0.727273
Median	0.512595	0.487591	0.340339	3.764997	1.677407	1.764709	1.000000
Maximum	1.145506	1.119279	0.791472	4.076109	2.043665	1.930292	1.000000
Minimum	−0.112607	0.225102	−2.602785	2.739490	1.194114	1.414706	0.000000
Std. dev.	0.403078	0.270355	0.550538	0.415164	0.187031	0.176530	0.447400
Observations	110	110	110	110	110	110	110
Correlation matrix							
$LOGCO_2$	1						
LOGBIO	−0.019672	1					
LOGFDI	−0.051118	0.0791235	1				
LOGGDP	0.626758	0.740238	0.082613	1			
LOGTR	0.770378	−0.435105	−0.035450	0.187956	1		
LOGURB	0.538100	0.805802	0.037031	0.975805	0.072578		
KP	0.106646	0.018784	0.4748306	0.198422	0.269617	0.135126	1

Note: CO_2 = Carbon dioxide emissions; BIO = biomass energy consumption; FDI = foreign direct investment; GDP = Gross domestic product proxy for economic growth; TR = trade ration; URB = urbanization; KP = Kyoto protocol.

Table 2
Results of panel unit root tests.

Variables	Level					First difference					Decision
	IPS	ADF	PP	CIPS	CADF	IPS	ADF	PP	CIPS	CADF	
LOG BIO	0.4635	9.5862	12.376	−2.484	−2.920	−6.5255*	56.572*	83.309*	−4.727*	−3.120*	I(1)
	[0.6785]	[0.4775]	[0.2607]			[0.0000]	[0.0000]	[0.0000]			
LOG GDP	3.9079	0.6613	0.4517	−2.155	−3.252	−2.8989*	25.165*	34.081*	−3.265**	−3.625*	I(1)
	[1.0000]	[1.0000]	[1.0000]			[0.0019]	[0.0050]	[0.0002]			
LOG CO_2	1.0866	7.2503	8.1553	−1.507	−1.769	−3.4226*	29.920*	40.671*	−3.209**	−3.209*	I(1)
	[0.8614]	[0.7016]	[0.6137]			[0.0003]	[0.0009]	[0.0000]			
LOG FDI	−3.2967	31.458	36.212	−3.494	−3.319	−5.3153	46.441*	319.95*	−5.467*	−3.891*	I(1)
	[0.0005]	[0.0005]	[0.0001]			[0.0000]	[0.0000]	[0.0000]			
LOG TR	0.3168	7.2133	16.631	−2.409	−1.949	−3.8361	33.777*	65.430*	−3.604*	−2.818**	I(1)
	[0.6243]	[0.7052]	[0.0829]			[0.0001]	[0.0002]	[0.0000]			
LOGURB	1.8011	4.8516	26.610	0.295	0.903	−2.8246	24.545*	32.486*	−3.780*	−3.780*	I(1)
	[0.9642]	[0.9009]	[0.0030]			[0.0024]	[0.0063]	[0.0003]			

Note: * and ** are significance level at 1% and 5% respectively.
IPS = Im Pesaran; ADF = Augmented Duckey Fuller; PP = Philips Pesaran; CIPS = Cross I'm Pesaran; CADF = Cross augmented Ducky Fuller.

(OIR) tests show that the instruments are not correlated with the disturbance term, so there is no heterogeneity problem. Overall, the results of the robustness check indicate that the study's model is well established. We also applied a fixed effects regression model (Table 4) for the six models as a robustness check, and the results are similar to those of the GMM model.

5.5. Pool mean group (PMG) analysis

Consistent with Sarkodie and Strezov (2018), we use the pool mean group (PMG) estimation approach to validate the GMM estimation model. The long-run estimation results of the PMG model reported in Table 5 show that the coefficients of GDP, GDP^2, and GDP cubed are positive, negative, and positive, respectively, in all models. In addition, the coefficient of biomass energy is negative, the impact of urbanization on CO_2 emissions is insignificant, the Kyoto protocol has a positive effect on environmental quality, and the impacts of the trade ratio and FDI on CO_2 emissions are insignificant. Consequently, the findings from the PMG estimation are consistent with the GMM estimation results.

6. Discussion

The N-shaped trajectory between income and pollution points to a provisional link, so the decrease in pollution that is due to growing income is a short-term effect; as soon as income increases in the BRICS countries, the level of pollution will start rising again. One possible reason for this effect could be the dramatic increase in economic growth that increases energy consumption, as the BRICS countries are heavily dependent on conventional sources of energy to meet the rising demand for energy. To ensure sustainable economic growth, these countries must create opportunities for biomass energy and other clean sources of energy, as shown in our econometric estimation. The

Table 3
The result of the Generalized method of moment (GMM) regression model.

Variables	Model (1)	(Model 2)	(Model 3)	Model (4)	Model (5)	(Model 6)
	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]
Constant	−8.222***	78.425***	−22.106***	−22.106***	−19.23***	−23.034***
	[0.000]	[0.000]	[0.001]	[0.001]	[0.002]	[0.001]
GDP	7.201***	72.626***	16.801***	16.801***	14.80***	18.179***
	[0.001]	[0.000]	[0.005]	[0.005]	[0.007]	[0.003]
GDP$^{\wedge 2}$	−2.073***	−22.03***	−4.225**	−4.225**	−3.86**	−4.806***
	[0.001]	[0.000]	[0.016]	[0.016]	[0.016]	[0.008]
GDP$^{\wedge 3}$	0.197***	2.169***	0.390**	0.390**	0.374**	−0.462***
	[0.001]	[0.000]	[0.022]	[0.022]	[0.017]	[0.008]
BIO	–	−1.214***	−1.742***	−1.742***	−1.561***	−1.598***
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
URB	–	–	−0.055	−0.055	−0.144	−0.256
			[0.704]	[0.704]	[0.291]	[0.111]
KP	–	–	–	−0.358***	−0.343***	−0.253***
				[0.000]	[0.000]	[0.000]
TR	–	–	–	–	0.255***	0.200**
					[0.002]	[0.029]
FDI	–	–	–	–	–	−0.028
						[0.102]
AR [1]	−3.31	2.42	−0.32	−0.32	−0.69	−0.28
AR [2]	−1.21	0.71	1.96	1.96	1.06	1.19
Sargan OIR	123.53	540.33	100.63	100.63	109.70	94.18
Instruments	61	60	60	60	60	60
Difference (null H = exogenous)	87.32	512.08	65.46	65.46	76.77	66.93
Observation	105	105	105	105	105	105
Number of groups	5	5	5	5	5	5

Note: GDP = Gross domestic product proxy for economic growth; GDP$^{\wedge 2}$ = square of GDP; GDP$^{\wedge 3}$ cube of GDP; BIO = Biomass energy consumption; URB = urbanization; FDI = foreign direct investment; TR = trade ration *** and ** show significance at the 1% and 5% respectively.

Table 4
The result of the fixed effect regression model.

Variables	Model (1)	(Model 2)	(Model 3)	Model (4)	Model (5)	(Model 6)
	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]
Constant	−36.57***	−40.03***	−52.22***	−58.70***	−56.96***	−57.71***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
GDP	33.45***	36.031***	46.27***	51.83***	50.17***	50.83***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
GDP^2	−10.13***	−10.66***	−13.89***	−15.66***	−15.16***	−15.37***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
GDP^3	1.020***	1.046***	1.370***	−1.555***	1.505***	1.526***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.01]	[0.01]
BIO	–	0.4658***	0.518***	0.386***	0.363***	0.360***
		[0.000]	[0.003]	[0.006]	[0.001]	[0.01]
URB	–	–	1.133***	1.621***	1.656***	1.689***
			[0.000]	[0.000]	[0.001]	[0.004]
KP	–	–	–	−0.159***	−0.179*	−0.179*
				[0.000]	[0.08]	[0.091]
TR	–	–	–	–	0.039	0.398
					[0.478]	[0.485]
FDI	–	–	–	–	–	−0.001
						[0.88]
R^2	0.62	0.70	0.76	0.77	0.78	0.78
F-test	23.61	27.52	28.48	25.07	21.31	18.22
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.0000]
rho	0.99	0.99	0.99	0.99	0.99	0.99
Observation	105	105	105	105	105	105
Number of groups	5	5	5	5	5	5

Note: GDP = Gross domestic product proxy for economic growth; GDP^2 = square of GDP; GDP^3 cube of GDP; BIO = Biomass energy consumption; URB = urbanization; FDI = foreign direct investment; TR = trade ration, *** and * show significance at the 1% and 10% respectively.

inverted U-shaped relationship holds for BRICS countries, as an initial increase in environmental pollution with economic development is due to a structural change in economic growth and technological advancement (Sarkodie, 2018), while the following decline in pollution with growing income can be attributed to people's demand for a clean environment, which results in the implementation of environmental laws, policies, and regulations that reduce environmental pollution (Sarkodie and Strezov, 2019b). Nevertheless, the N-shaped relationship suggests that the inverted U-shaped relationship is temporary and that pollution increases again with rising income, perhaps because poor countries tend to care little about environmental sustainability and prefer economic growth. That demand translates into exploitation of natural resources and the manipulation of environmental regulations and industry standards to lure (polluting) industries from developed countries (Sarkodie and Strezov, 2019a). The re-emergence of the scale effect could also dominate the composition and technical effects in a country that cares little about environmental protections (Balsalobre-Lorente et al., 2018). Our results are in line with those of Pal and Mitra (2017), who confirmed the N-shaped trajectory between growth and CO_2 emission for India and China, a departure from the EKC hypothesis. Our findings are also similar to those of Onafowora and Owoye (2014), who reported an N-shaped trajectory between growth and CO_2 emissions for China, Egypt, Brazil, Mexico, Nigeria, and South Africa. This evidence reveals that policies have inclined more to economic development than to environmental protection. As a result, CO_2 emissions are still increasing rapidly, along with economic growth.

Table 5
The Long run result of the Pool Mean Group (PMG) regression model.

Variables	Model (1)	(Model 2)	(Model 3)	Model (4)	Model (5)	(Model 6)
	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]	Coefficient [prob]
GDP	232.48**	3924.4*	34.232**	2.7433*	55.645**	66.615*
	[0.019]	[0.000]	[0.019]	[0.000]	[0.019]	[0.000]
GDP^2	−33.761**	−434.86*	−5.5039**	−0.7320*	−6.362**	−7.3084*
	[0.012]	[0.000]	[0.0214]	[0.000]	[0.021]	[0.000]
GDP^3	1.548**	16.062*	0.2630**	0.0397*	0.2417**	0.2669*
	[0.010]	[0.000]	[0.013]	[0.000]	[0.018]	[0.001]
BIO	–	−0.8187*	−2.9326*	−1.3598*	−0.1207**	−0.2994*
		[0.000]	[0.000]	[0.000]	[0.032]	[0.000]
URB	–	–	13.975**	−0.3363	−8.644	0.7922
			[0.037]	[0.563]	[0.1556]	[0.5245]
KP	–	–	–	−0.1796*	−0.2723*	−0.8560*
				[0.000]	[0.000]	[0.000]
TR	–	–	–		0.7830	0.2203
					[0.5362]	[0.327]
FDI	–	–	–			−0.0072
						[0.2236]
Observation	105	105	105	105	105	105
Number of groups	5	5	5	5	5	5

Note: GDP = Gross domestic product proxy for economic growth; GDP^2 = square of GDP; GDP^3 cube of GDP; BIO = Biomass energy consumption; URB = urbanization; FDI = foreign direct investment; TR = trade ration, * & ** show significance at the 1%, 5 and % respectively

Biomass energy's negative effect on CO_2 emissions is observed in BRICS countries, suggesting that an increase in biomass energy consumption reduces environmental pollution. This behavior of biomass energy is in tandem with a low carbon development hypothesis related to effective ways to control pollution. The lesson from our findings is that biomass energy behaves like a renewable energy source, which helps control pollution by reducing CO_2 emissions in BRICS countries. This source of energy is plentiful in the BRICS countries, and combustion of biomass is "carbon neutral," as re-growing plants removes an amount of CO_2 emissions from the atmosphere that corresponds to the amount released to the atmosphere when they are burned, so net CO_2 emissions are zero (Shahbaz et al., 2017). Sarkodie and Adams (2018) contended that renewable and clean technologies contribute to a clean environment, while fossil fuel energy technologies increase environmental pollution. These findings correspond to those of Dogan and Inglesi-Lotz (2017) and Shahbaz et al. (2017), who agreed that biomass energy behaves like clean energy, although Shahbaz et al. (2018) and Solarin et al. (2018) argued that biomass is a source of fossil fuel that increases environmental pollution.

Trade worsens environmental quality in the BRICS countries since, as their economies become more open, trade barriers drop and environmental standards are weakened to boost trade activities. BRICS countries like China, India, and Russia want to expand trade relationships with other countries, but the use of machinery for the production of exported goods is unlikely to be environmentally friendly, as these countries commonly use outdated machinery that not only consumes energy but is also more polluting than more modern machinery. In addition, a mutual trade agreement may mean transferring dirty technologies to BRICS countries because of their lax environmental laws, hence adding to pollution (Danish et al., 2017c; Sarkodie and Strezov, 2019b). Trade activities also increase energy demand, leading to reliance on imports of conventional energy sources like coal, oil, and gas. However, unlike renewable energy, these conventional sources of energy are finite and unsustainable, and their use increases environmental pollution (Destek and Sarkodie, 2019).

7. Conclusion

This study's goal is to determine whether biomass energy helps to reduce CO_2 emissions. For this purpose, the study analyzes the effect of biomass energy on CO_2 emissions in BRICS countries. Second-generation panel unit root tests are used to check the stationarity of the series, and the GMM approach is used for panel data estimation from 1992 to 2013.

The empirical results feature five key findings:

i. An N-shaped relationship is found between income and pollution.
ii. Biomass energy behaves like a clean energy source and helps to reduce environmental pollution.
iii. Trade is a significant factor in increasing environmental pollution.
iv. BRICS countries achieved a substantial improvement in environmental quality after becoming signatories to the Kyoto protocol.
v. FDI and urbanization have insignificants effect on environmental pollution.

These empirical results have important policy implications. The presence of N-shaped curves for the countries in our study suggests that, after using environmental policies to fight degradation at the intermediate income range, continued economic growth eventually decreases environmental quality. Environmental degradation cannot be controlled by increasing income, as the populace's demand for a clean environment as income rises is temporary. Therefore, it is up to policymakers to ensure the consistent implementation of environmental laws, policies, and regulations.

The literature's findings on the role of biomass energy in environmental pollution are ambiguous, but our estimations reveal that biomass energy is a source of clean energy in BRICS countries. Therefore, we urge the governments of BRICS countries to allocate more funds and encourage research and development into exploitation of biomass energy resources. Opening trade has led to additional pollution in BRICS economies by increasing the demand for energy; increasing the production of biomass energy is a better choice for meeting this demand than importing conventional fuels because biomass energy is a carbon-neutral energy source in BRICS countries. Strict environmental standards should also be set to discourage the import of dirty goods.

Nomenclature

BRICS	Brazil, Russia, India, China, South Africa
CO_2	Carbon dioxide emissions
EKC	Environmental Kuznets curve
FDI	Foreign direct investment
GMM	Generalized method moment
GDP	Gross domestic product
LLC	Levin Lin Chu
OLS	Ordinary least squares
R & D	Research and development
PMG	Pooled mean group

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Declaration

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References

Adewuyi, A.O., Awodumi, O.B., 2017. Biomass energy consumption, economic growth and carbon emissions: fresh evidence from West Africa using a simultaneous equation model. Energy 119, 453–471. https://doi.org/10.1016/j.energy.2016.12.059.

Al-Mulali, U., Saboori, B., Ozturk, I., 2015a. Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy 76, 123–131. https://doi.org/10.1016/j.enpol.2014.11.019.

Al-Mulali, U., Weng-Wai, C., Sheau-Ting, L., Mohammed, A.H., 2015b. Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. Ecol. Indic. 48, 315–323. https://doi.org/10.1016/j.ecolind.2014.08.029.

Arellano, M., Bond, S., 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev. Econ. Stud. 58, 277. https://doi.org/10.2307/2297968.

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., Farhani, S., 2018. How economic growth, renewable electricity and natural resources contribute to CO2emissions? Energy Policy 113, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050.

Baležentis, T., Streimikiene, D., Zhang, T., Liobikiene, G., 2019. The role of bioenergy in greenhouse gas emission reduction in EU countries: an environmental Kuznets Curve modelling. Resour. Conserv. Recycl. 142, 225–231. https://doi.org/10.1016/j.resconrec.2018.12.019.

Bildirici, M.E., 2014. Relationship between biomass energy and economic growth in transition countries: panel ARDL approach. GCB Bioenergy 6, 717–726. https://doi.org/10.1111/gcbb.12092.

Bilgili, F., Öztürk, İ., Koçak, E., Bulut, Ü., Pamuk, Y., Muğaloğlu, E., Bağlıtaş, H.H., 2016. The influence of biomass energy consumption on CO2 emissions: a wavelet coherence

approach. Environ. Sci. Pollut. Res. 23, 19043–19061. https://doi.org/10.1007/s11356-016-7094-2.
Cherni, A., Essaber Jouini, S., 2017. An ARDL approach to the CO2 emissions, renewable energy and growth nexus: Tunisian evidence. Int. J. Hydrog. Energy, 1–11 https://doi.org/10.1016/j.ijhydene.2017.08.072.
Danish, Zhang, B., Wang, B., Wang, Z., 2017a. Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. J. Clean. Prod. 156, 855–864. https://doi.org/10.1016/j.jclepro.2017.03.203.
Danish, Zhang, B., Wang, Z., Wang, B., 2017b. Energy production, economic growth and CO2 emission: evidence from Pakistan. Nat. Hazards 90, 1–24. https://doi.org/10.1007/s11069-017-3031-z.
Danish, Wang, B., Wang, Z., 2017c. Imported technology and CO2 emission in China: Collecting evidence through bound testing and VECM approach. Renew. Sustain. Energy Rev., 1–11 https://doi.org/10.1016/j.rser.2017.11.002.
Danish, Khan, N., Baloch, M.A., Saud, S., Fatima, T., 2018a. The effect of ICT on CO2 emissions in emerging economies: does the level of income matters? Environ. Sci. Pollut. Res. 25, 22850–22860. https://doi.org/10.1007/s11356-018-2379-2.
Danish, Wang, B., Wang, Z., 2018b. Imported technology and CO2 emission in China: collecting evidence through bound testing and VECM approach. Renew. Sust. Energ. Rev. 82, 4204–4214. https://doi.org/10.1016/j.rser.2017.11.002.
Destek, M.A., Aslan, A., 2017. Renewable and non-renewable energy consumption and economic growth in emerging economies: evidence from bootstrap panel causality. Renew. Energy 111, 757–763. https://doi.org/10.1016/j.renene.2017.05.008.
Destek, M.A., Sarkodie, S.A., 2019. Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. Sci. Total Environ. 650, 2483–2489. https://doi.org/10.1016/j.scitotenv.2018.10.017.
Dogan, E., Inglesi-Lotz, R., 2017. Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: empirical evidence from the panel of biomass-consuming countries. Energy 138, 721–727. https://doi.org/10.1016/j.energy.2017.07.136.
Dogan, E., Ozturk, I., 2017. The influence of renewable and non-renewable energy consumption and real income on CO2emissions in the USA: evidence from structural break tests. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-017-8786-y.
Dong, K., Sun, R., Dong, X., 2018. CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China. Sci. Total Environ. 640–641, 293–302. https://doi.org/10.1016/j.scitotenv.2018.05.322.
Farhani, S., Ozturk, I., 2015. Causal relationship between CO2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ. Sci. Pollut. Res. 22, 15663–15676. https://doi.org/10.1007/s11356-015-4767-1.
Grossman, G.M., Krueger, A.B., 1991. Environmental impacts of a North American free trade agreement. Natl. Bur. Econ. Res. Work. Pap. Ser. No. 3914, 1–57. https://doi.org/10.3386/w3914.
Halkos, G.E., 2003. Environmental Kuznets Curve for sulfur: evidence using GMM estimation and random coefficient panel data models. Environ. Dev. Econ. 8, 581–601. https://doi.org/10.1017/S1355770X03000317.
Ito, K., 2017. CO2 emissions, renewable and non-renewable energy consumption, and economic growth: evidence from panel data for developing countries. Int. Econ. 151, 1–6. https://doi.org/10.1016/j.inteco.2017.02.001.
Katircioglu, S.T., 2015. The impact of biomass consumption on CO2 emissions. An empirical investigation from Turkey. Int. J. Clim. Chang. Strateg. Manag. Artic. Inf. 7, 348–358. https://doi.org/10.1108/IJCCSM-06-2014-0077.
Moomaw, W.R., Unruh, G.C., 1997. Are environmental Kuznets curves misleading us? The case of CO2 emissions. Environ. Dev. Econ. 2, 451–463. https://doi.org/10.1017/S1355770X97000247.
Onafowora, O.A., Owoye, O., 2014. Bounds testing approach to analysis of the environment Kuznets curve hypothesis. Energy Econ. 44, 47–62. https://doi.org/10.1016/j.eneco.2014.03.025.
Owusu, P.A., Asumadu-Sarkodie, S., 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng. 3, 1–14. https://doi.org/10.1080/23311916.2016.1167990.
Pal, D., Mitra, S.K., 2017. The environmental Kuznets curve for carbon dioxide in India and China: growth and pollution at crossroad. J. Policy Model https://doi.org/10.1016/j.jpolmod.2017.03.005.
Panayotou, T., 1993. Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development. ILO Working Papers.
Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econ. 47, 36–37. https://doi.org/10.1002/jae.951.
Sarkodie, S.A., 2018. The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa? Environ. Sci. Pollut. Res. 25, 21993–22022. https://doi.org/10.1007/s11356-018-2347-x.
Sarkodie, S.A., Adams, S., 2018. Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa. Sci. Total Environ. 643, 1590–1601. https://doi.org/10.1016/j.scitotenv.2018.06.320.
Sarkodie, S.A., Strezov, V., 2018. Empirical study of the environmental Kuznets curve and environmental sustainability curve hypothesis for Australia, China, Ghana and USA. J. Clean. Prod. 201, 98–110. https://doi.org/10.1016/j.jclepro.2018.08.039.
Sarkodie, S.A., Strezov, V., 2019a. A review on environmental Kuznets Curve hypothesis using bibliometric and meta-analysis. Sci. Total Environ. 649, 128–145. https://doi.org/10.1016/j.scitotenv.2018.08.276.
Sarkodie, S.A., Strezov, V., 2019b. Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci. Total Environ. 646, 862–871. https://doi.org/10.1016/j.scitotenv.2018.07.365.
Shahbaz, M., Rasool, G., Ahmed, K., Mahalik, M.K., 2016. Considering the effect of biomass energy consumption on economic growth: fresh evidence from BRICS region. Renew. Sust. Energ. Rev. 60, 1442–1450. https://doi.org/10.1016/j.rser.2016.03.037.
Shahbaz, M., Solarin, S.A., Hammoudeh, S., Shahzad, S.J.H., 2017. Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the United States. Energy Econ. 68, 548–565. https://doi.org/10.1016/j.eneco.2017.10.004.
Shahbaz, M., Balsalobre, D., Shahzad, S.J.H., 2018. The influencing factors of CO2 emissions and the role of biomass energy consumption: statistical experience from G-7 countries. Environ. Model. Assess. https://doi.org/10.1007/s10666-018-9620-8.
Solarin, S.A., Al-Mulali, U., Gan, G.G.G., Shahbaz, M., 2018. The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. Environ. Sci. Pollut. Res., 1–17 https://doi.org/10.1007/s11356-018-2392-5.
Tiba, S., Omri, A., 2017. Literature survey on the relationships between energy, environment and economic growth. Renew. Sust. Energ. Rev. 69, 1129–1146. https://doi.org/10.1016/j.rser.2016.09.113.
Wang, Z., Danish, Zhang, B., Wang, B., 2018. The moderating role of corruption between economic growth and CO2 emissions: evidence from BRICS economies. Energy 148, 506–513. https://doi.org/10.1016/j.energy.2018.01.167.
Zaman, K., Abdullah, A. Bin, Khan, A., Nasir, M.R.B.M., Hamzah, T.A.A.T., Hussain, S., 2016. Dynamic linkages among energy consumption, environment, health and wealth in BRICS countries: green growth key to sustainable development. Renew. Sust. Energ. Rev. 56, 1263–1271. https://doi.org/10.1016/j.rser.2015.12.010.
Zhang, S., Liu, X., Bae, J., 2017. Does trade openness affect CO2 emissions: evidence from ten newly industrialized countries? Environ. Sci. Pollut. Res., 1–10 https://doi.org/10.1007/s11356-017-9392-8.